Space Weather Technical Forecast

Issued on Monday, 25 December 2023 at 12:47 Local

This technical forecast provides a four-day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: Numerous CMEs observed: Chance G1 periods through second half of four-day forecast. Chance of M-class flares throughout.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Solar activity increased notably in the past 24 hours, with a previously quiet X-ray trace at GOES16 punctuated by three recent M-class flares, with two of these falling in the past 24 hours: (an M2.9 peaking at 24/1118UTC); an M2.6 peaking at 24/1649UTC from AR3529; and finally a long-period M1.1 from over the southeastern limb at 24/1951UTC.

There were seven sunspot regions on the visible disc. The main changes in the period were a proliferating and then spreading trend in AR3530 near centre-disc, however this appears to have stalled and has not resulted in significant flaring. This sunspot group finished the period as a Cai/Beta. The other region of note was AR3529 in the southwest, with some minor pores remaining visible in advance of the main penumbral spot. There is a small filament immediately west of this feature, and flaring in the sunspot group is arcing across this which has likely helped generated some of the many Coronal Mass Ejections (CMEs) seen in the past 24 hours. This sunspot group is analysed as an Eho/Beta.

The energy stored as regions of strong contrast in the magnetic field on the Earth-facing side has suffered something of a domino effect in the past 24 hours, with the Sun divesting itself of many of the filaments that had emerged in the run-up to the Christmas period, perhaps partly due to AR3529's flaring across the southern end of one such filament.

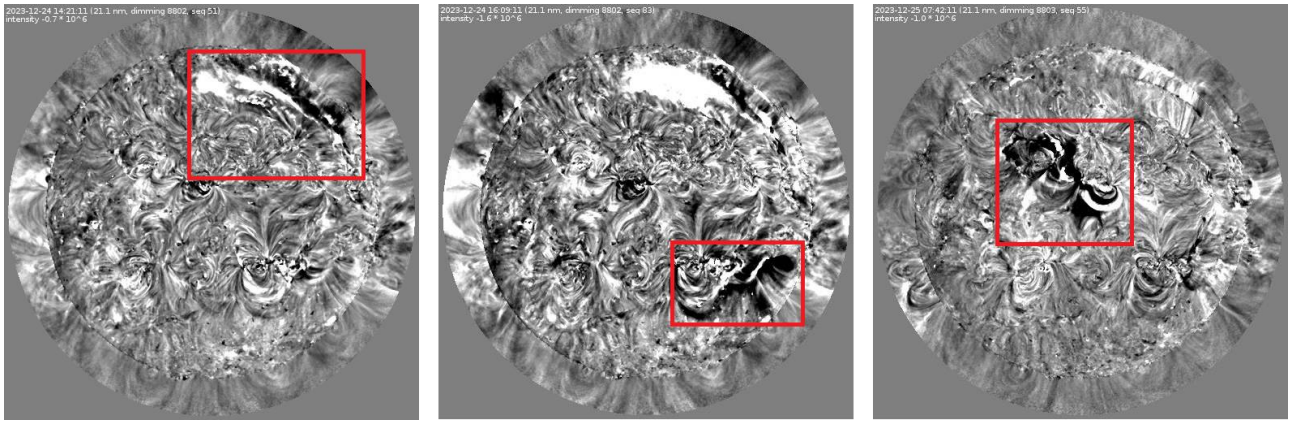

Figure 0: Time-integrated AIA211 dimmings processed by SIDC ROB, showing the three main events of note in the past 24 hours. The first two feature as glancing blow CMEs on and after 27 December, and the third will very likely add to this roster given the now visible partial halo emanating from behind Lasco C2's occulting disc.

The tally of CMEs is now large and carries high uncertainty for their frequency and probable inter-connectivity. For a (near-)full roster, please see the geomagnetic activity section. The most

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noteworthy events are summarised as:

Firstly, a large filament eruption from the northwest disc around the start of the current reporting period (i.e. around 24/1200UTC). This has been analysed extensively, and although it largely passes above the ecliptic plane, there are a significant number of MOSWOC Enlil ensemble members that have glancing blows from around the middle of the UTC day of 27 December.

Secondly, a high coronal dimming visible on AIA211 from the southwest disc (but not on H-Alpha), around 24/1430UTC. This feature has been analysed as crossing mainly below and ahead of the Sun-Earth line around the turn of the UTC day 27 into 28 December, but again a glancing blow is considered possible.

Thirdly, a high coronal dimming in AIA211 around 25/0700UTC occurred to the immediate west of AR3533. This was not tied to any filament on H-alpha, but a CME appears to have been released. Provisionally, this is likely the most directly-aligned of any of the candidate CMEs with Earth, and early C2 imagery suggests a faint partial halo with a slight eastward bias. Further imagery is awaited for analysis.

Solar Wind / Geomagnetic Activity: Solar winds, as measured by ACE and DSCOVR at L1, were Slightly Elevated, and while an observed weak enhancement may have originated in a weak coronal hole, this is inconclusive with no clear observed source.

The solar wind speed gradually rose through the period from 400 to 450km/s, with the density showing a similar trend in rising from single figures ppcc into low double figures. The IMF showed the opposite tendency in falling gradually from an early peak of 8nT, with the north-south component erratic and with a range of +7 and -6nT. The phi angle was mainly positive (away from the Sun) but changed to negative after 25/0500UTC, which was accompanied by a slight calming of the other solar wind traces.

The net result of the above solar wind measures was for provisionally Quiet geomagnetic activity, falling from an early high of Kp '2+'.

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux was at Background levels.

GOES16 high energy (greater than 2MeV) electron flux was at Normal Background levels in light of the recent weak solar wind-derived geomagnetic enhancement. The 24-hour fluence was below Active throughout and declining, with the 25/0001UTC observation being 3.20e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Low to Moderate activity is forecast, with an ongoing Chance of isolated M-class X-ray flares.

Solar Wind / Geomagnetic Activity: There has been a glut of CMEs in recent hours, and there is now high uncertainty in the phasing of impacts during the second half of the four-day period especially. At least two have Earth-directed components, with a probable third awaiting imagery, for a full discussion please see the geomagnetic activity section.

Mainly quiet geomagnetic conditions should give way to a Chance of Minor Geomagnetic Storm G1 periods on and after Wednesday 27 December as a result of CME influence. No fast winds feature.

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is at Background and likely to persist at this level, but with a Slight Chance of increasing given any further notable flares

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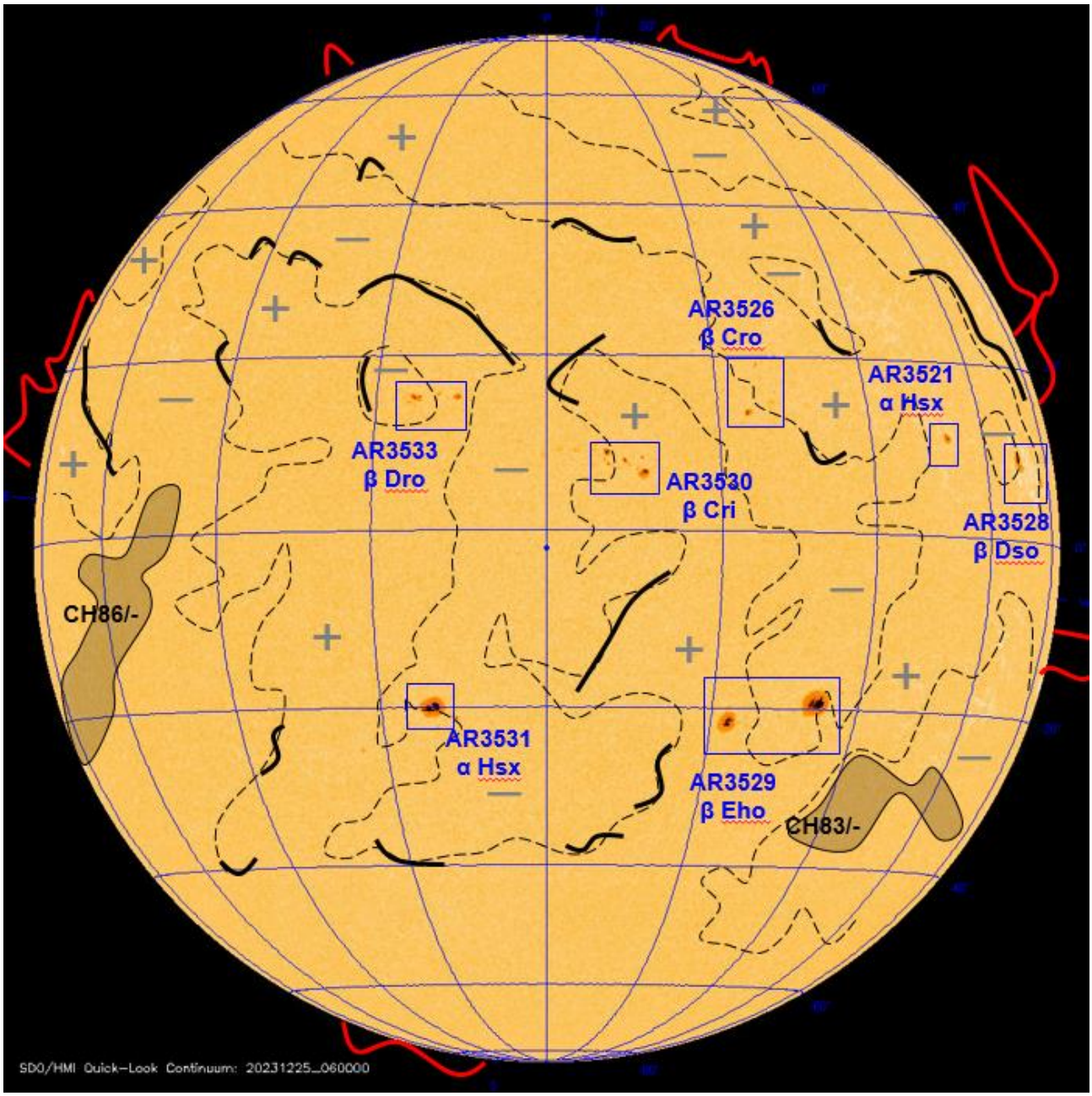
from AR3529 or other regions on the disc, especially as these move into the western hemisphere.

GOES16 high energy electron flux is expected to persist at mainly Normal Background levels, with the associated fluence remaining below the Active level.

Figure 1. Solar Analysis Valid 25/0600UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

No fast winds feature in the forecast, with the current minor fast wind having likely peaked and soon fading.

The tally of CMEs, by contrast, is now large and carries high uncertainty for their frequency and probable inter-connectivity. Limb-based events have not been included here as an attempt at brevity.

Firstly, a large filament eruption from the northwest disc around the start of the current reporting period (i.e. around 24/1200UTC). This has been analysed extensively, and although it largely passes above the ecliptic plane, there are a significant number of MOSWOC Enlil ensemble members that have glancing blows from around the middle of the UTC day of 27 December.

Secondly, a high coronal dimming visible on AIA211 from the southwest disc, around 24/1430UTC. This was flanked by M-class flares from AR3529, but the time the CME emerges from the occulting disc of Lasco C2 is a better fit for the event described above. This feature has also been analysed as crossing mainly below and ahead of the Sun-Earth line around the turn of the UTC day 27 into 28 December. Thirdly, a much fainter CME emerged on the coat-tails of the above from around 24/1900UTC, probably tied to the M2.6 from AR3529, with this felt to be ahead and below the Sun-Earth line to no effect.

Fourthly, a filament eruption from the north-central disc around 24/2330UTC, possibly triggered as the ribbon flare from the earlier northwest filament reached a second feature here and destablised it. This is possibly linked to a narrow CME seen heading north during the early hours of 25 December. This has been analysed and felt too narrow and north to feature in the forecast. Fifthly, a mid-C class flare from AR3529 around 24/2330UTC produced a faint CME heading apparent south and west of the Sun-Earth line. This has been analysed and is thought to pass ahead and below of the track of the Earth's orbit to no effect.

Sixthly, a high coronal dimming in AIA211 around 25/0700UTC occurred to the immediate west of AR3533. This was not tied to any filament on H-alpha, but a CME appears to have been released. Provisionally, this is likely the most directly-aligned of any of the candidate CMEs with Earth, and a partial halo with a slight eastward bias is now becoming visible on the current UTC morning's Lasco C2. Further images are needed to attempt analysis, however this provisionally appears to carry an Earth-directed component.

All considered - and with imagery pending for the sixth CME listed above - at least two of the above events have possible Earth-bound components. MOSWOC Enlil runs have been relatively volatile in their treatment of these, perhaps because of the sheer number of events. The model itself is now felt to be offering better treatment of fast winds - i.e. they now appear to be absent, as forecast, which increases confidence in CME transit times to 1AU. Earth may well see glancing impacts from above an below the ecliptic from 27 December, else it could 'thread the needle' and be an island of relative calm despite numerous near-misses.

Despite the complexity of inputs, the actual distilled forecast is much simpler: geomagnetic activity should be Quiet over the Christmas period. There is then a Chance of G1 conditions from 27 December, although confidence is lower than is typical for this range.

Geo-Magnetic Storm	**Level**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC)**	**Day 2 (00-24 UTC)**	**Day 3 (00-24 UTC)**	**Day 4 (00-24 UTC)**
Probability (Exceedance)			**(%)**	**(%)**	**(%)**	**(%)**

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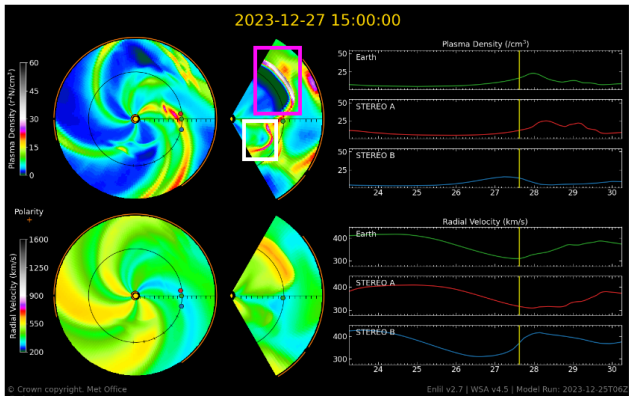
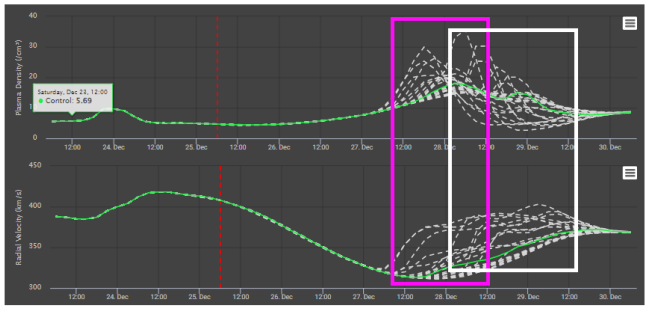
Minor or Moderate	**G1 to G2**	No	1	1	30	30
Strong	**G3**	No	1	1	1	1
Severe	**G4**	No	1	1	1	1
Extreme	**G5**	No	1	1	1	1

Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
12/1732	Partial?	Filament	NW	850km/s	27/1200UTC +/-12h	Low confidence, glancing blow
12/2224	Partial?	Filament	SW	572km/s	28/0600UTC +/-12h	Low confidence, glancing blow
	Partial	Filament	NE Centre			Imagery awaited

Figure 2: Latest MOSWOC Enlil and ensemble, showing large CMEs above (24/1200UTC filament, magenta box) and below (24/1500UTC high coronal dimming, white box) the solar equatorial plane, with the Earth avoiding both in some solutions, but more likely seeing some form of glance on or after 27 December. A third CME from the 25/0700 NE centre disc does not yet feature, but will very likely add to this maelstrom of actvity later in the four-day forecast.





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Radio Blackouts - X-Ray Flares:

Low to Moderate activity is forecast, with an ongoing Chance of isolated M-class flares.

There are seven sunspot regions currently on the disc, including large region AR3529 in the in the southwest, which was the source of two M-class flares on 24 December. This is an open group of two mature leader and trailer spots, but with some slight complexity around its leader, possibly due to interaction with a filament ahead of the spot. The other main flare risk is AR3530 in the north-centre disc, which has shown recent growth but is otherwise a relatively simple region. The other five regions remain smaller and simpler, with a lower but non-zero chance of producing M-class flares.

A further M-class flare was observed over the southwest limb on 24 December, and it remains to be seen if this is the precursor to a more active region rotating onto the disc. Along with a distinct area of magnetic looping visible on AIA171 in the northeast, this may suggest the potential for further arriving regions.

Recently active AR3529 is present throughout the four-day forecast period, and the well-spread nature of the remainder of sunspot regions ensures no sharp falls in daily flare risk are expected. Any assessment as to the effects of arrivals over the eastern limb is withheld until they present for analysis.

X Ray Flares Probability	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M Class	Yes	50	50	50	50
Very Active	R3 to R5 X Class	No	5	5	5	5

Figure 3: Past 24 hours to 25/1200UTC sources of C-class flares and above, as recorded by PROBA2 and processed by SIDC ROB. Note that the accordance is well spread, and includes a possible arriving southeast limb region.

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Solar Radiation Storms - (High Energy Protons):

The high energy (greater than 10MeV) proton flux observed by GOES16 has been at Background, and is likely to persist at these levels. There is a slight chance of enhancement if any further M-class flare activity was to occur from AR3529, or from any of the other spots, particularly as they move into the western hemisphere.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ S1**	No	5	5	5	5
Very Active	**≥ S3 ***	No	1	1	1	1
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

High Energy Electrons Event (≥ 2MeV):

High energy electron flux (greater than 2MeV) observed by GOES16 is at Normal Background, With any recent solar wind enhancement subdued, and no further coronal hole features in the forecast, mainly background flux is expected to persist for much of the period, although brief periods of Moderate flux are likely. There are then the CME glancing impacts possible from 27 and 28 December, and these are likely to further suppress observed flux at GEO until after this four-day period.

The associated 24-hour fluence is expected to persist below Active (1e8 pfu) as a result of the above. Regarding MOSWOC REFM, the fact that the current possible fast wind enhancement is not forecast nor a persistent feature, as well as the presence of at least two CMEs later in the period, will mean that although the initial trend is accepted, the rational is probably incorrect. MOSWOC REFM should not be followed in the second half of the period due to the CMEs, although the forecast low fluence count is probably correct.

GEO Electron Environment Probability (Exceedance)	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ 2 MeV ≥ $1x10^8$**	No	1	1	1	5
Very Active	**≥ 2 MeV ≥ $1x10^9$**	No	1	1	1	1

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